Discussion before the Wireless Section, 18 May, 1927.

Mr. L. B. Turner: Amongst the many pleasing points in the outfit described, there recur to me, in order of complexity, (1) the use of boarding standing out clear of the wall (Fig. 2), for fixing instruments, etc.; (2) the "polygon of errors" method of deriving the self-capacity of a coil from a number of necessarily not wholly concordant observations (Fig. 26); and (3) the use of a "neutrodyned" triode to prevent all reaction between the two high-frequency oscillators which together excite the rectifier in the acoustic generator (Fig. 16). Amongst the commoner uses of the triode—amplifying, rectifying and oscillating—its extraordinarily perfect unilateral property, whereby grid circuit may influence anode circuit without anode circuit influencing grid circuit, is often lost sight of. The practical difficulty—the severity of which always surprises me when I meet it—of keeping two nearly isochronous oscillators sensibly independent, is completely overcome in the author's arrangement. In considering the design of a laboratory generator of acoustic currents, the heterodyne type adopted by the author offers great advantages over the simpler acoustic triode oscillator in respect of wide range of acoustic frequencies, and of ease in obtaining output amplitudes not varying much with frequency. The author mentions the latter point, and it would, I think, add to the value of the description of his generator of heterodyne type if he could give some typical curves or figures showing its performance in this respect. In Fig. 23 a method is recommended for obtaining adjustable and measured values of simultaneous direct and alternating currents, through an inductance, such as an acoustic transformer winding, while it is subjected to a bridge measurement. I do not appreciate the implied necessity for the extra complication of the bridge within a bridge. No doubt the author has not proceeded from the simple to the complex without reason; and I should be interested to learn why a direct arrangement such as that shown in Fig. A is not satisfactory. The alternating-current p.d. across

X would be indicated directly by the thermionic voltmeter, and the d.c. current in it would be calculated from the reading of the d.c. ammeter. The 1 or 2 megohms of shunt provided by the thermionic voltmeter would usually be quite negligible, and could in any case be allowed for. In conclusion, I should like to add a word on the question of d.c. supplies, to which the author refers early in the paper. In my laboratory at Cambridge we have chosen the opposite course to his. We have a large 4V battery for filament lighting, connected to all tables by solid, bare copper wire $\frac{1}{4}$ inch in diameter. This has, of course, often to be supplemented by small local batteries, but the number required is much less than if no common battery were available. The anode supplies, too, are taken to a large extent from a common 220V tapped battery. With a dozen or so of new students, the difficulty of avoiding ruinous damage resulting from misconnections may easily be imagined. The arrangement we have come to is shown in Fig. B. The rule is that no connection shall be made between the two batteries (4 V and 220 V) except by means of a single special plug and cord located at the switchboard. This cord is provided with (i) a 3·5 V, 0·2 A fuse lamp; (ii) a wire resistance of about 200 ohms in series—to protect the fuse from rush of current on closing the H.T. supply across, possibly, several microfarads of bypass condenser at the tables; (iii) a 200V, 15W indicator lamp, which glows more or less brightly when a misconnection has blown the fuse. What one really does want in addition is some convenient form of fuse, or simple quick-acting cut-out, competent to protect a delicate milliammeter. I should be glad to hear of such a device.

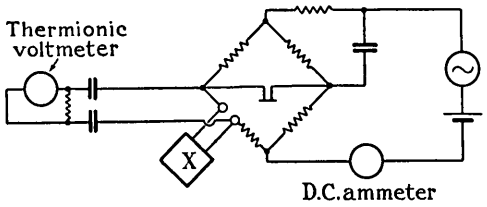

FIG. A.

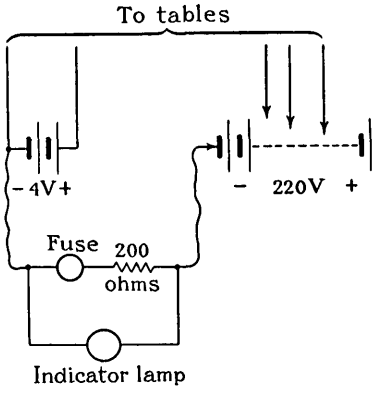

FIG. B.

Mr. P. R. Coursey: I have at the works of the Dubilier Condenser Co. a laboratory in which is carried on a somewhat similar class of work to that which the author has described. Naturally there are differences, because the two companies have different objects in view, with the result that to a certain extent the general lay-out and arrangement are somewhat different, although there are features common to both. The switchboard arrangement which we use purely for laboratory circuits consists of two parts (illustrated by lantern slides), the left half comprising power circuits, and the right half battery circuits. The left half is wired through to the main switchboard of the works, and the right half is connected mainly to local batteries. Of the right-hand half there are two portions, one dealing with H.T. batteries and the other with L.T. (6-volt) batteries. The L.T. battery throw-over switches are so arranged that in their lower position the batteries are connected through to terminals at the bottom of the switchboard where cross-connections can be made to the bench circuits, while in their upper positions the switches connect up the charging circuit. There are two voltmeters permanently mounted on this board for reading the battery voltages while on load. They are connected to the various batteries by a selector switch and also by a plug and sockets. On the main battery board of the works, which is also linked up with the laboratory circuits, we have the cross-connections arranged with plugs and sockets, the various circuits terminating on a two-pin plug at the end of a flexible connection, and the various batteries terminating on plug sockets. A series of throw-over switches is also fitted for enabling the various batteries to be put on to charge, or on to their discharge circuit. There are 6-, 12-, 50-, 100-, 200- and 300-volt batteries connected to this board. In the laboratory the circuits which are run to terminal boards on each of the work benches are connected to the terminals on the switchboard which I have already mentioned and two groups of circuits are arranged. The common low-voltage battery connection to all benches to which the author refers is probably very convenient, but we have not adopted it as we generally use the low-tension battery circuits definitely switched on from the board to the specific bench terminals required. In some cases, where an entirely insulated low-tension battery must be used with the minimum capacity to earth, a portable 6-volt battery is employed on the bench itself. All the power circuits from the laboratory terminate at switches on the main power board of the works and can there be fed from various machines giving different supply voltages and different frequencies from 50 up to 800 cycles per sec. We have also provided in the laboratory a small rack of batteries for local use, and a transformer giving up to 50 000 volts which can be used locally for any pressure tests of a special nature which it is desirable to carry out in the laboratory, as distinct from tests in the works. Of the special testing arrangements to which the author refers, the condenser-leakage test is rather interesting to me as it is very similar to, but not quite the same as, one I have used for some years, wherein I have always put the test condenser in the grid circuit of the valve with a negative bias (Fig. C). The general arrangement is similar to that shown in the paper, with a milliammeter (mA) in series with the anode battery B_2 and the

test condenser in the grid circuit of the valve. The condenser under test, marked C_x, can be connected to the terminals provided, and there is a negative voltage in series with it (B_3) which may be anything from 100 to 300 volts or more, according to requirements. The key K is joined directly between the grid and filament of the valve and provides a circuit to charge the condenser initially to the voltage of the battery B_3. After pressing the key K, this charge on the condenser gradually leaks away and so gradually makes the grid more and more negative, so that the deflection on the milliammeter slowly falls from the initial reading down to zero or, I should say, down to a value which is usually zero, but if the leakage of the condenser C_x is very small the leakage on the valve holder may hold the grid at some potential not quite so negative as it would otherwise reach. In this case the reading of mA may not fall quite to zero. The portion of the circuit shown in heavy lines in Fig. C must be particularly well insulated. Normally, this method gives a very simple test which is of the same type as that referred to by the author. If he has made any comparisons between the two methods, I should be interested to have some figures regarding their relative advantages. While I

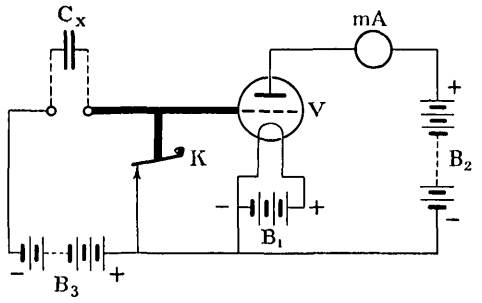

FIG. C.

have tried the arrangement which he shows in the paper, I have not used it to anything like the same extent as the one shown in Fig. C. This arrangement can also be used as a test for quickly rejecting condensers which have an insulation lower than a specified amount. If, on pressing the key, the milliammeter reading falls very rapidly to zero, then it is known that the insulation of the condenser is below a certain amount. With the particular arrangement we have, this figure is usually of the order of 750 megohms. I should like to refer to one point which appears to apply to the arrangement shown in Fig. C and also to that shown by the author. It would appear that if time readings are taken, as he suggests, the time of passage of the needle between two marks on the milliammeter scale would give, directly, values of the quantity "megohm-microfarads." Such values are a much truer test of the dielectric of the condenser than the actual insulation resistance of the condenser. This quantity may also be quoted as ohm-farads, or written ΩF. The value for any given dielectric is independent of the condenser capacity. If the author could give some information regarding the type of valve which he has found most successful for use with his insulation test, it would, I think, add to the value of the description given in the paper. The arrangement of his audio-frequency source is a very simple one. Can he give any more detailed particulars of this arrangement, as compared with the direct oscillator? Mr. L. B. Turner mentioned one or two advantages, but perhaps the author might also amplify the comparison between these two types of audio-frequency sources. In one or two cases we have found that the straight-diode voltmeter which the author mentions is rather more convenient for many measurements than the triode voltmeter which he describes in more detail. Can he give some further comparisons as to the relative merits of those two meters? For the most accurate measurements with galvanometers, we found it desirable to put in a concrete pillar specially for the support of the galvanometer, particularly for measurements of very high insulation resistances. The type of capacity bridge mentioned in the paper, which we also use for special tests, is a very useful one. We, however, have added two adjustable condensers, one connected to each arm of the bridge and adjustable up to 1μF (total). By that means capacity readings by difference can be taken with considerable accuracy at 1 000 cycles, and approximate power-factor measurements can also be made. Substitution measurements of this type are, in my opinion, more reliable than measurements taken across the bridge, since any lack of equality in the ratio arm is eliminated.

Prof. W. C. Clinton: It may be of interest to record that for some 20 years we have used at University College a plug board in which there are no flexible leads at all. The board consists of a slate slab with vertical bars at the back and horizontal bars at the front, as usually arranged. The plugs screw in to the back bars and thus pull into firm contact with the front bars. These are of channel section against the slate, each one forming a slot as long as the bar, in which another metal bar slides. This bar is drilled with holes having a pitch slightly different from that of the holes in the enclosing bar, with the result that when a plug is screwed home no other plug can be inserted in that bar. The board is made in two sections, one for each pole, with the corresponding sliding bars linked together by an insulated connection. No inadvertent short-circuit has yet occurred on these boards.

Mr. E. B. Moullin: On page 196 it is stated that all the rough measuring instruments have a single scale only. Does the author consider there is advantage in this? I dislike single-range instruments for a testing-laboratory equipment, because I find it entails frequent changes during most tests. I always convert single-range instruments into multi-range instruments before they are issued for use, and I am surprised to find the author appears to disagree with this procedure. I should like to hear further details of the construction of the high-resistance units of the decade boxes made by the General Radio Co. and mentioned on page 198. The author refers to a wattmeter and its corrections, but tells us nothing about the instrument itself. It must necessarily be a very sensitive instrument: is it a reflecting instrument of his own construction or some pivoted pattern of high sensitivity? The author's device for testing insulation resistance is most ingenious, but he does not tell us why it was found necessary to

substitute this for a simple galvanometer test. Personally I use a potential difference of 500 volts derived from a.c. mains and rectified by a small receiving triode, and then one may readily detect a leak of, say, 50 000 megohms. The rectified source is very convenient, because it cannot supply a current greater than a few milliamperes, even on short-circuit. I should have imagined the valve device would have been more satisfactory if the charged condenser had been applied between the grid and filament. The grid would then be given a large negative bias sufficient to suppress entirely the anode current: when the condenser voltage had fallen to some definite amount, anode current would begin to flow. The arrangement would in effect be a "slide-back voltmeter." I understand that the thermo-couple milliameters are arranged as standards for measuring high-frequency currents and are permanently calibrated. The calibration is apt to be upset by changes of atmospheric temperature, because the galvanometer circuit is mainly copper and has therefore a considerable temperature coefficient. I should like to draw the author's attention to an automatic compensating device I use to eliminate the temperature correction. The heater has in parallel with it a shunt the resistance of which at 0° C. is equal to that of the heater: the temperature coefficient of the shunt is made equal to that of the galvanometer circuit. The shunted instrument is then independent of temperature-changes, whatever be the temperature coefficient of the heater itself.* With respect to valve voltmeters, I should like to know why the author insists (on page 203) that "To secure low power consumption and independence of frequency, the grid should be connected directly to the circuit to be measured and ample bias used." Usually I prefer to work with an inductance coupling, because if the instrument is direct-coupled its great sensitivity often tempts one to cut down the power in the circuit to an absurdly small value and then the power used by the voltmeter may not be negligible. The graphical method of determining self-capacity, illustrated in Fig. 26, is most ingenious and useful. The author makes no mention of the Meissner method of measuring self-capacity by immersing the coil in paraffin oil. I find this method most useful and satisfactory, because the whole determination is made by a single measurement which does not require a frequency measurement. Of course the author may reply that many coils must not be immersed, but on the other hand there are many coils which may be, and I think the method is a very practical one for routine tests in the laboratory. I am surprised the author makes no reference to resistance potential-dividers for high-frequency work. I find them invaluable adjuncts for laboratory measurements because they are so much more readily adjusted than an inductive coupling. With regard to high-frequency resistors, I should like to know why the author uses separate units which plug into a holder, in preference to a decade box. Obviously it is a nuisance to have a collection of loose units and the system would not have been adopted without some reason.

Mr. J. H. Reyner: While the methods described in the paper are of considerable interest, and none of them is, in my opinion, too academical for practical purposes, the equipment would seem to be beyond the reach of many works laboratories. At the same time, the author gives many details of great practical value, which suggest methods of achieving similar results with less expensive apparatus. He mentions the inter-dependence of frequency and output in the rectifying system of the beat low-frequency oscillator, and states that by using cumulative grid rectification serious variations in the output result. This is an extremely interesting point, because I have had trouble myself with this type of oscillator on which little practical information has hitherto been available. On page 203 there is a further reference to this question, it being stated that condenser-coupled valve voltmeters are unsuitable where independence of frequency is required. Is this an established fact or is it simply a corollary

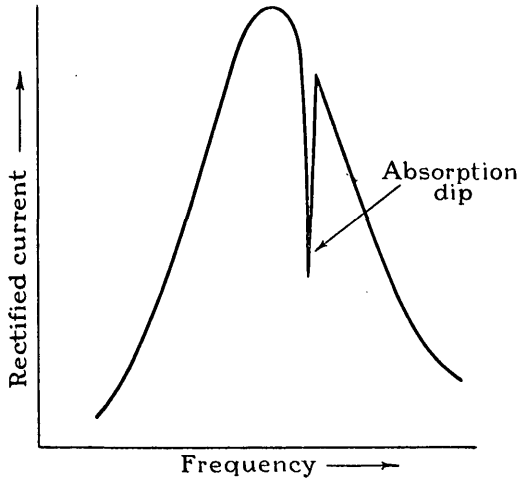

FIG. D.

from the author's previous results in connection with the development of the oscillator? There are two quite simple methods which I should like to mention in connection with the paper. One concerns wave-meters for use as frequency standards. Mention has been made of a method of utilizing a calibrated quartz crystal as a source of standard frequency, which is a system that I have used for some time with a certain amount of satisfaction. The method adopted is to tune an oscillator exactly to the frequency of a quartz crystal having a frequency of the order of 500 kilocycles, and then to synchronize a second oscillator to a frequency of one-tenth of the first oscillator. Harmonics of the second oscillator can then be picked up on the original oscillator, and thus a series of check points are obtained separated by comparatively small frequency differences. For tuning the first oscillator exactly to the quartz crystal and also for obtaining a check on this standard frequency from time to time, a simple check-meter is used. It consists of a tuned pick-up circuit having a rectifying crystal in series with a microammeter shunted across a portion of the circuit (about one-third) and the quartz crystal in question shunted across the whole circuit. An ordinary resonance curve on the microam-

* E. B. MOULLIN: "Radio-frequency Measurements," p. 48.

meter is obtained by varying the frequency of the oscillator to be calibrated. The resonance point is somewhat indefinite, but at the particular frequency which resonates with the quartz crystal an absorption effect occurs, causing a very sharp dip in the resonant curve, as shown in Fig. D. This method, in addition to its usefulness in calibrating an oscillator, is of considerable value in measurements involving an accurate indication of resonance, for example the measurement of very small capacities. The oscillator condenser is accurately calibrated, and the resonance point is obtained with and without the unknown capacity in parallel. The difference between the two readings is the capacity of the extra condenser. It is possible to obtain a high order of accuracy by this method in measuring very small capacities. The other matter I should like to mention is a system of detecting high-frequency oscillations without the necessity of setting up a valve voltmeter. The method is one suggested by the Bureau of Standards, Washington, some time ago, and has the advantage that it introduces very little extra damping into the circuit. A crystal is connected to the high-potential end of the circuit, and a sensitive microammeter is shunted across the crystal itself (Fig. E). This

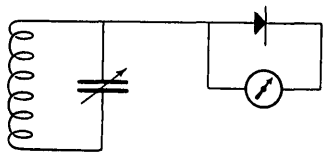

FIG. E.

gives very good results, but of course it depends upon capacity to earth, which must therefore be properly under control to avoid discrepancies in the readings. My experience shows that this can easily be done, and sensitive and accurate results are obtainable without the trouble of installing expensive a.c. instruments.

Mr. L. H. Bainbridge-Bell: A previous speaker mentioned the difficulty of testing receiving sets in presence of electrical interferences from neighbouring machinery. My own experience in trying to trace such sources may be of general interest. Interference in a receiver using a frame aerial was experienced when a certain line of shafting (driven by an electric motor) was running. The usual remedies (i.e. connecting the armature to earth through large condensers) produced no result. It was found that the noise continued after the motor had been switched off, and disappeared only when the shaft had stopped. The fault was traced to a d.c. leak from the mains which caused the stanchions carrying the shafting to have different potentials: the resistance of the connection between them, via the shaft and the shaft bearings, varied when the shaft was turned. The fault was cured by bonding all the stanchions together. In another instance, interference from a transmitter, which was being tested on a continuous load, was noticed to be varying rhythmically in strength in synchronism with the rotation of another line shaft. Here, as before, the trouble was eliminated by bonding the shaft bearings. In some cases it has been found that although connecting the brushes (through condensers) to earth has had no effect, connecting them to the carcase of the motor has been very successful. The reason for this has not been investigated. Generally, in tracing and eliminating sources of interference, it was found that the only quick and satisfactory method is for the telephone leads to be extended so that *one person* can switch the motor on and off and connect condensers to it while actually listening to the results in the telephones. If thought necessary, a screened transformer can be inserted in the telephone lead at the receiver end. Mr. L. B. Turner asked for particulars of a fuse which would blow at a very small current. It has been found possible to use the foil employed in Mansbridge condensers as a fuse for this purpose. On a previous occasion I was able to construct a fuse of this material which would carry only about 10 milliamperes, but lately I have been trying to repeat this and have not been able to make one to blow at less than 50 milliamperes. The reason for this difference is possibly the different types of foil employed by different makers. As it is impossible to see whether the foil has fused or not, if fusing is suspected the fuse has to be tested electrically.

Mr. W. L. McPherson: The author appears to prefer heterodyne oscillators for very low frequencies. We have recently done a great deal of work at periodicities down to 15 cycles and we found that the straight oscillator using iron-core coils gave very good results and was on the whole more trustworthy than a heterodyne oscillator, even one in which precautions had been taken to avoid the production of harmonics due to beats between harmonics of the heterodyning frequencies. I note that the author complains of a slight variation in the wave-length when using a G.R.C. condenser. We had the same experience, and the trouble was traced to the fact that the moving vanes moved relative to the spindle very slightly every time the dial was brought up against the stops. In regard to the valve test-set, has the author any arrangement by means of which he can test the efficiency of the valve as a detector? One or two speakers have referred to the question of "mush" in works. The laboratory with which I am concerned is subjected to a very great amount of interference from motors, shafting, etc. We have found that for measurement purposes a very great deal can be accomplished by connecting the apparatus in a cage of ordinary steel netting of about 1 in. mesh. That was much more successful than we expected it to be, and we found it was quite possible to make radio-frequency measurements on receiving apparatus inside the cage with a transmitter giving out about 5 kW of radio-frequency energy into an artificial antenna 30 ft. away.

Capt. B. S. Cohen: The existence of such works laboratories as that of the author should convince purchasers of broadcast receivers of the efficient design and reliability of sets of British manufacture. I propose to confine my remarks to the heterodyne oscillator (see pages 201 and 202). There are now three types of heterodyne oscillator of which particulars have been published, viz. the Dollis Hill type described by Messrs. Aldridge and West and myself in the I.E.E. *Journal* * and in more detail by myself in the *Post Office Electrical*

* *Journal I.E.E.*, 1926, vol. 64, p. 1023 also *Proceedings of the Wireless Section*, 1926, vol. 1, p. 206.

Engineers' Journal (1927, vol. 19, p. 309). The second set is that made by the British Broadcasting Corporation and described by Mr. Kirke in the *Wireless World*, and now we have the set described in the present paper which embodies features of both the other sets. In the Dollis Hill set both high-frequency oscillators are amplified and it has been found advisable to incorporate this feature in the portable form which at first was built without high-frequency amplification. The author suggests that we were favoured by fortune in overcoming various difficulties, but I would state with all due diffidence that the only favours granted by fortune were those which generally accompany elaborate and detailed measurement. No difficulty is experienced in building replica sets to the details given in the papers referred to, to give results in accordance with those published. The obtaining of a constant output over the audio range is not found to be one of the most difficult problems. If the transformers are of proper design with plenty of stalloy core cross-section and well-designed interleaved windings, and if the last stage of audio-frequency amplification has the anode coupling described, consisting of an inductance of the order of 0·2 henry in series with a variable resistance, there is no difficulty in getting a flat characteristic. To obtain purity of wave-form has been found to be the more difficult problem, and here the avoidance of all interaction is essential. The use of individual chokes and condensers in each H.T. feed was found to be of great importance, as also was efficient screening. It is also of course essential to use valves which can deal with the output, and we find that valves of the L.S. 5a type are desirable in the last audio-frequency stage. It has not been found necessary to go higher than 70 000 to 80 000 cycles per sec. for the oscillator frequency, and some of the problems are simplified by keeping this frequency low. The author gives no quantitative measurements of wave-form purity. Quantitative measurements of the wave-form purity of the Dollis Hill oscillator now indicate a maximum amplitude harmonic of the order of 3 per cent.

Mr. M. G. Scroggie (*communicated*): Regarding the audio source concerning which a number of inquiries have been made, the following additional details refer to the circuit diagram, Fig. 16. The coupled coils in compartments (1), (2), (3) and (4) are in each case wound on bakelite formers having slots with inside and outside diameters $1\frac{3}{16}$ in. and $1\frac{3}{4}$ in. respectively and width $\frac{1}{8}$ in. Each coil is wound, in a separate slot, with $\frac{1}{2}$ in. spacing between slots. The tapped coil in (2) is in two sections as in (1) and (3); each of these six sections consists of 60 turns of 26 d.s.c. wire. The coupling coil in (2) has one turn, and the coils in (4), from top to bottom, 40 turns of 24, 185 of 32, and 90 of 28, all double silk-covered. The remaining coils, in the anode circuits of (1) and (3) and in (5), are chokes with 1 000 turns of 44 d.s.c. wire wound in a single slot. Valves (1), (2) and (3) are of moderate impedance, (4) and the first two in (6) of high impedance, and the last valve of extra-low impedance. An external additional stage has now been constructed, containing two L.S.5 valves in parallel. The filament battery is 6 volts, anode 150 volts, and grid bias to (2) and the first two of (6) 3 volts, to (4) 13·5 volts, and to the last valve 22·5 volts. The grid bias to (4) is critical. The anode resistors are of 45 000 ohms, and the remaining components are quite normal, except the coupling condensers in (6) which are 2 μF. The capacities of the various condensers are as follows:—

Condenser	Capacity, $\mu\mu$F
A	1 000
B	100
C	500 (Max.)
D	25 ,,
E	500 ,,

Condenser "D" has now been moved to compartment (1) where it is connected across the grid and anode ends of the coils. The output curve rises rapidly to about 100 cycles and remains substantially level to 4 000 cycles, where it dips slightly and rises above the original level at 7 000 cycles. It has been found that the frequency of the two oscillators is too high; about 100 000 cycles is a more useful figure—in fact one should use the lowest frequency at which a change of 7 000 cycles can be obtained without appreciable variation in strength of oscillation. An important point in the reduction of harmonics is the adjustment of filament temperature, but this can only be ascertained by trial. Before using the apparatus it is switched on for at least 10 minutes to allow the frequency to settle down, as the drift is quite large at first.

Mr. P. K. Turner (*in reply*): Before making detailed comments on the discussion, I should like to express my gratitude to the speakers, who have, by their remarks and descriptions of alternative methods, added greatly to any value that the paper may possess.

Mr. L. B. Turner asks for details of the frequency-output characteristic of the acoustic generator. Unfortunately, I have not available a copy of this curve, but some further details of this instrument will be found in Mr. Scroggie's communication. Mr. Turner also raises a question as to the necessity of the suggested double bridge for measurement of the inductance of coils carrying direct current. Certainly his suggested method (Fig. A) is much simpler, and it may only have been careless arrangement that gave me trouble from earth effects with similar circuits and led to experiments with the double bridge. As indicated, this work was still incomplete at the time of submitting the original paper, and no opportunity has yet occurred of completing it. Mr. Turner's arrangements for avoiding serious breakdown with common batteries are very sound, but in my view the possibility of cross effects makes it unwise to use common batteries where precision work on amplifiers of high magnification may have to be done.

Mr. Coursey's arrangements for power supply are on a more ample scale than mine, but seem to be of the same general type. With regard to the comparison between his type of condenser leakage tester and that described in the paper, there would appear to be little to choose as regards performance, while I note that his type requires two independent batteries of 100 volts or more as against one in mine: it was, in fact, this point which led to the adoption of this type. As to the

choice of valve, little work has been done—any valve having a fairly high μ value seemed effective, provided its insulation was really good. Mr. Coursey asks for further details of the beat audio source, as compared with a direct oscillator. There really seems little to add to the reasons given on page 202, except that the beat method also makes it easier to get a wide range of frequency with easy adjustment. He also inquires as to the diode and triode voltmeters. The former has a high input impedance of 50 000 to 500 000 ohms; but the latter has one even higher, which is sometimes important. The diode type has an evenly-divided scale except for voltages below about 2, and can be made to read from about 1 up to several hundred volts; the triode, of usual design, has a more or less even scale of $(\text{volts})^2$ and extends from about 0·02 to 6 V. It is difficult to make a constant resistor of high value for the diode type which maintains an unchanged impedance at high frequencies: this does not apply to the triode. Lastly, in my experience the diode type has a rather greater error for complex wave-forms. Obviously the choice between the two is a matter involving the particular work on hand at the moment.

Mr. Moullin raises a point as to rough measuring instruments. I certainly agree that it is pleasant to have all instruments of the multi-range type; but in my department economy has to be considered, and the reason for selecting single-range meters was in order to have plenty, in fact a dozen or so per worker. One 3-range instrument will not replace three single-range ones, for it cannot be used in three places at once. In the majority of cases where rough instruments are used, they are to check the constancy of, say, a filament voltage or an anode current during a series of tests. When measurement as such is required a more accurate instrument is used, and these, being fewer in number, are mostly multi-range, as described. The G.R.C. decade boxes referred to by Mr. Moullin consist of Ayrton-Perry coils of manganin wound on flat bakelite formers. The wattmeter is a pivoted instrument, with two current windings for series-parallel connection, and a voltage multiplier. It thus has the four ranges shown in Fig. 15 of the paper. As to the comparative merits of the condenser tester and the ordinary galvanometer method, my opinion is that the former has overwhelming advantages. It requires only a robust pivoted meter, it uses much less voltage (which is sometimes of importance), and it requires no precautions to deal with the charging current, which is fatal to a galvanometer unless care is taken. In fact, the valve method can be used in a workshop, while the galvanometer method cannot. Since its accuracy is ample for the work, in my opinion there is no serious comparison between the two. The choice of the particular wiring chosen has already been explained in reply to Mr. Coursey. Mr. Moullin's excellent shunted thermo-junction has been known to me since the publication of his book referred to. It was not mentioned in the paper as I have not yet had occasion to use it. Perhaps the paper was not quite clear as to the input connections of valve voltmeters. The words " . . . grid should be connected direct to the circuit to be measured . . . " referred only to the absence of condensers and " grid-leak," and were not intended to exclude the use of inductive coupling. The Meissner method of measuring self-capacity is ingenious and, in some circumstances, most valuable; but in my opinion its validity requires deep consideration except in the case of coils with practically no solid dielectric. It hardly seems suitable for recommendation as a general method for use in the type of laboratory described. The high-frequency resistors described were for precision work, and it is my view that separate, fixed resistors are more suitable for this purpose (on account of smaller reactance, dead-end effects, etc.) than any type of variable high-frequency resistor.

In reply to Mr. Reyner, the unsuitability of condenser-coupled valve voltmeters where independence of frequency is desired is simply a matter of the reactance of the condenser. If the phase angle and capacity of the valve, and the phase angle of the necessary leak, are accurately known at all frequencies, the correction may of course be calculated or, in most cases, made negligible; but the point is of importance, e.g. in calibrating on 50 cycles per sec. (as is often done) a meter designed for use at radio frequencies. The quartz crystal method of detecting resonance is of course very valuable, but in my view the " one-ended " crystal method described by Mr. Reyner is far inferior to the use of a valve voltmeter employed as described on page 208.

I am grateful to Mr. Bainbridge-Bell for his suggestion of using Mansbridge coated paper for delicate fuses, the need of which I myself have felt just as severely as has Mr. L. B. Turner.

Mr. McPherson refers to testing the efficiency of valves used as detectors. This matter has been gone into very thoroughly by Mr. F. M. Colebrook,* and by taking a grid-voltage/grid-current curve and deriving therefrom the parameter b as described in the reference one can get a very good comparison, bearing in mind that this b is more or less a measure of the grid depression produced by a given a.c. input, and that therefore the μ and/or mutual conductivity of the valve must also be considered.

I must disavow the suggestion attributed to me by Mr. Cohen. It was not suggested that Mr. Cohen and his co-workers were favoured by fortune in overcoming difficulties; rather that the favour was in not having any, for none were referred to in their paper. Frankly, I am gratified to be able to surmise from Mr. Cohen's remarks that he also had his troubles in the initial stages of design and experiment. His suggestions in regard to design are of great value.

* F. M. Colebrook: " The Rectification of Small Radio-frequency Potential Differences by Means of Triode Valves," *Experimental Wireless* 1926, vol. 2, pp. 865 and 946.